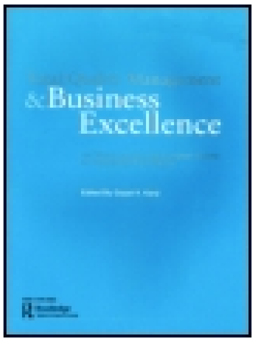

Routledge
Taylor & Francis Group

Total Quality Management & Business Excellence

ISSN: 1478-3363 (Print) 1478-3371 (Online) Journal homepage: http://www.tandfonline.com/loi/ctqm20

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To cite this article: Yujin Jeong & Byungun Yoon (2018): Application of Taguchi model to valuation of information security technology considering security quality failure, Total Quality Management & Business Excellence, DOI: 10.1080/14783363.2018.1468246

To link to this article: https://doi.org/10.1080/14783363.2018.1468246

Published online: 24 Apr 2018.

Total Quality Management, 2018
https://doi.org/10.1080/14783363.2018.1468246

Application of Taguchi model to valuation of information security technology considering security quality failure

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As interests in intangible assets in a digital economy have been growing, technology valuation is becoming increasingly more important in information technology management. Most existing valuation methods do not reflect the unique characteristics of technology. Thus, this paper aims to suggest an approach for technology valuation that considers the nature of information security technology. First, technological value is evaluated by scoring value factors that are used to analyse the intrinsic characteristics and application of technology. Second, to evaluate the market value, the expected profit of the technology will be deduced by using an income approach, reflecting on the characteristics of information security products and services. The weighted sum of factors from the previous scoring process plays a role in adjusting the expected profit. Third, the Taguchi loss function is applied to calculate the amount of social loss incurred due to the lower quality level of security. The final result of technology valuation is presented by integrating the expected profit and social loss. The proposed approach is illustrated with a case of safe symmetric key algorithm, one of information security technologies in Korea. The results of technology valuation will provide objective information for technology transfer and the selection of R&D projects.

Keywords: information security technology; security quality; social impacts; information technology valuation; income approach; Taguchi loss function; R&D project selection

1. Introduction

Intangible assets, such as one's reputation, knowledge, and technology, can be regarded as representative assets in a knowledge-based society, where ample resources can be used to create value for firms (Volkov & Garanina, 2007); they play an important role in a firm, enabling it to become more competitive in the market. Since these assets in the form of intellectual property are usually the result of research and development in firms and institutions, they may provide a strong foundation for creating products, services, or business models that can be transferred to others or to business partners (Amorim & Souza, 2011). Thus, evaluating knowledge assets accurately is necessary to maximise profits and to minimise the time and effort required to transfer technology.

Several concepts related to measuring the value of technology have been studied in depth. These concepts can be categorised based on the following aims of valuing technology: evaluation that measures only the level of technology (Ryu & Byeon, 2011; Benson & Sage, 1993); the assessment of social and economic effects (Wyk, 2010); and valuation executed to estimate monetary value (Jeon & Shin, 2014; Kumbaroglu, Madlener, & Demirel, 2008). First, the goal of technology evaluation is to appraise the intrinsic value of

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technology through the index approach, scoring, the analytic hierarchy process, a growth curve, and so on (Jeong & Kim, 1997; Ryu & Byeon, 2011). Second, technology assessment extends the range of analysis to the social, political, and economic impacts of technology based on experts' opinions in general (Spreng, 2002). Finally, technology valuation estimates monetary value through income, cost, the profit approach, real options (Park & Park, 2004; Vega-Gonzalez, Qureshi, Kolokoltsev, Ortega-Martinez, & Saniger Blesa, 2010), and expert participation (Daim & Intarode, 2009) based on the premise that technology can be traded. Most technologies have unique characteristics in terms of their life cycles as well as the extent of their influence in society, the economy, and so on, depending on the areas and types of these technologies (Hu, Li, Wen, & Yan, 2016). For example, information and communication technology (ICT) has a short life cycle and is quickly converted into next-generation technology. In terms of the type of technology, generic technology that becomes a foundation in a given area can be expected to have a higher impact because it has the potential to generate various relevant lines of products and services. Thus, the distinct features of technology should be adequately reflected in the technology valuation process.

In particular, information security technology requires more effort when it comes to considering the characteristics of technology because quality failure in security is directly connected to a national security issue with increased threats to information security (Silic & Back, 2016). Recently, cyber-attacks have greatly diversified due to the advancement of information technology, and the losses continue to mount up. For people to effectively respond to a security threat, they need to devise a plan for developing innovative technology and supporting commercialisation after exploring promising and valuable information security technology (Smith, 2004). A promising technology in the field of information security can be identified by calculating the technology's monetary value while also considering its social and economic impacts on quality failure; the issues relevant to security quality can then be addressed, leading to the improvement of industrial competitiveness. However, despite the unique features of technology, no customised methodology for technology valuation has been proposed, and no attempts have been made to measure the impact of information security technology. The valuation of information security technology needs to reflect both its monetary value and its social impacts.

This paper illuminates the question of how to perform technology valuation that reflects the distinct characteristics of technology. Since the information security technology is closely related to information technology, they co-evolve and are no longer complementary. Moreover, it has a major effect on national security and is affected by regulations. One must consider these attributes when assessing the value of technology. Therefore, this research suggests a technology valuation methodology for information security technology that combines the income approach for extracting the monetary value of technology and the Taguchi loss function for assessing the social impact of technology quality. The proposed approach consists of technology and market evaluation, as well as an analysis of the ripple effect of technology. This means that the intrinsic value of technology and the expected profit generated from a technology-embedded product or service is evaluated based on the income approach. After the technology is evaluated through a scoring model, the monetary value of the technology is estimated using the income approach, which calculates the expected value when selling products or services that apply information security technology. Although many attempts have been made to assess technology, such as the market approach, cost approach, and income approach (Chiesa, Gilardoni, & Manzini, 2005; Doerr, Gates, & Mutty, 2006; Baek, Sul, Hong, & Kim, 2007; Schuh, Schubert, & Wellensiek, 2012; Wirtz, 2012), they have focused on the cash flow estimated from a financial statement. However, estimating a future cash flow and interest rate is difficult and may lead to a biased estimation. In addition, the existing approaches can hardly evaluate the value of technology that has great social impact. Therefore, this paper suggests a guideline for calculating the future cash flow of technology by considering the intrinsic characteristics and marketability of technology as well as the correlation between the intrinsic characteristics and marketability, considering the ripple effect of technology. If the relation between a technology and the market, as well as the social impact of the technology are considered when one is calculating the technology's monetary value, it helps to define the value of the technology by considering all of the perspectives of both buyers and suppliers in transacting the new technology in the future.

Within the framework of this study's research methodology, the intent of this paper is to solve the research problem through the income approach and the Taguchi loss function. The income approach is a methodology for technology valuation that concentrates on analysing the profitability of technological assets. It converts the value of technology to the value at the time that technology-embedded products/services generate earnings. In particular, the income approach estimates the value of technology via the net cash flow and the optimal interest rate, and it mostly depends on expert opinions. However, this paper provides a guideline, such as indicators, for measuring the net cash flow and optimal interest rate, which is helpful for assessing technological value objectively and clearly. In addition, while the Taguchi loss function has been widely used for the quality management of a product or service in various industries (Quigley & McNamara, 1992; Li, 1998; Kethley & Waller, 2002; Dura & Isac, 2009; Taner & Sezen, 2009), this paper transforms the Taguchi loss function to evaluate the socioeconomic damage resulting from the technology itself. Information security technology causes a great deal of social and economic loss, such as cyber terror and information leakage, which may be expanded to failure in the security of the government when information security is failing. Because it is important to quantitatively estimate these types of loss to intuitively understand them, the basic concept of the Taguchi loss function can be similarly applied to this case. Whereas previous studies on quality management defined quality as the degree to which a set of inherent characteristics fulfils an established requirement, the Taguchi loss function defines quality as loss that a product causes to society after being produced, other than the losses stemming from intrinsic functions. Therefore, this paper's aim is to extend the application range of the Taguchi loss function from a product or service to technology. Thus, the characteristics of quality are transformed, such as confidentiality, integrity, and availability, according to the technological features of the information security technology. Moreover, a loss stemming from failures in information security is defined as the ripple effect of technology, which helps recognise the socioeconomic impact of technology. It enables one to assess the value of technology based on technological features, marketability, and influences on society.

The niche point of this paper is to assess the value of technology by considering the unique characteristics of technology, especially focusing on information security technology with a high socioeconomic impact and a high degree of application. Since the value is estimated in the form of the monetary value based on the socioeconomic loss stemming from the failure of information security, as well as the commercial value, it can be applied to other technology of which quality management is important due to its great impact and public benefit. In other words, the proposed approach considers all influencing factors when one is evaluating the value of technology, such as the inherent value, unique characteristics of technology, application, and publicness, which can be identified via indicators in evaluating technology and the loss function. Thus, it serves as a guideline for evaluating high-impact and value-added technology by modifying indicators related to the unique characteristics of technology. The proposed approach contributes to research and development (R&D) planning in firms and institutions as well as to decision-making for technology commercialisation by valuing technology itself as well as its socioeconomic impacts as a form of economic value. In Korea, although the level of information technology is high and the internet penetration rate is very high, information security is relatively vulnerable. In light of this, Korea has an increasing interest in developing new information security technology considering its market size and social impacts. An R&D project for information security technology should evaluate its profitability and social losses based on the failure of information security. Thus, the technology-customised valuation will help to predict promising technology and to evaluate the R&D priority. Moreover, the proposed approach will support the decision-making process for establishing a strategy that suggests the direction for information technology development or business planning in companies and research institutions.

This paper is structured as follows: Section 2 investigates the characteristics of the information of security technology, which is the subject of this research, and reviews the relevant studies on technology valuation and the Taguchi loss function. Then, the basic concept and overall process of technology valuation are explained in Section 3. The proposed approach to information security technology is applied to a case study in Section 4, and conclusions from this research are provided along with the direction for policy-making in Section 5.

2. Background

2.1. *Information security technology*

The rapid growth of ICT and societal interdependency can cause serious potential threats to information security (Sund, 2007). Thus, information security technology that can be used to protect the cyber environment and users' assets has several unique characteristics. First, three basic principles of information security technology are confidentiality, integrity, and availability, which are directly linked to the value of information assets (Vidalis & Kazmi, 2007). Since using information security assets might cause a loss of confidentiality, a breach of integrity, and a loss of availability, the technology should be developed to manage the information security process under the principles.

Second, the relationship with advanced ICT needs to be comprehensively considered because information security technology evolves as ICT advances (Preez, 2007). In particular, information security technology is a collection of ICT that requires core technologies including cipher and authentication, and advanced technology such as a wired/wireless network, Internet, and terminal technology. In the recent past, most businesses were integrated with information technology, and required more powerful security of personal information to prevent diverse types of damage.

Third, it has become necessary to analyse the economic impact since information security technology is rapidly growing and has a high added value. In particular, advances in ICT and the increase in the value of information have caused a growth in the demand for information protection in perspective of quality management (Martin, Bulkan, & Klempt, 2011); this is why the technology is considered a high-value-added technology. Therefore, information security technology can be expected as a core technology that will encourage the future growth of information communication industries since the characteristics of information communication as well as information protection are integrated.

Fourth, the public concern must be reflected because it is directly connected to guaranteeing national security and it can also affect related law or policy-making. If the development of information protection technology depends on foreign technology, domestic classified information could possibly leak by collaboration with foreign companies or governments. Therefore, it is important to investigate the social and economic value of the added value of information protection technology.

At the same time, the classification of information security technology was defined in this study to evaluate and determine the R&D priority. Information security technology can be classified into generic technology, security technology for systems, networks, platforms and devices, application service security technology, and evaluation and management technology for information. Since a lot of technology in all categories can be a candidate for a promising technology, potential technology will be appraised and selected in accordance with the current trends of technology development.

2.2. *Technology valuation*

Information assets, including information security technology, are needed to predict the impact and consequence of security incidents. Since most business operations rely on information technologies, any threat to a business's information technology directly threatens the business (Tatar & Karabacak, 2012). Accidents stemming from a failure in security could mean the loss of credibility and economic damage, which is why risk needs to be analysed when one is valuing information security technology (Foroughi, 2008; Bayaga, Flowerday, & Cilliers, 2013). From this perspective, the return on security investment, which refers to the benefit of security investment by determining the value of assets damaged by security breaches and the cost of its impact, has been proposed for technology valuation (Foroughi, 2008). Similarly to information security technology, energy technology that provides high public benefit is evaluated via system dynamics, a Monte Carlo simulation, and the real option method to reflect the various aspects surrounding renewable energy due to its massive socioeconomic and technological impact (Jeon & Shin, 2014; Kumbaroglu et al., 2008). In environmental technology or biotechnology, technology valuation has been carried out to identify promising technology via a multi-criteria decision-making technique. When appraising information security technology in this study, it was appropriate to estimate the monetary value based on the income approach (valuation) while also including an assessment that can analyse the social and economic impacts.

To estimate the monetary value of a technology, four approaches are used: the cost perspective, income perspective, market perspective, and real options. The cost perspective estimates future profit based on the cost of acquiring assets (Poh, Ang, & Bai, 2001), and the income perspective focuses on examining profitability through the net cash flow and discount rate (Graves & Ringuest, 1991; Park & Park, 2004). With regard to the market perspective, the expected value is calculated by aggregating all of the transactions of technological assets in the marketplace to obtain the current transaction value for technology valuation purposes. Real options differ from traditional methods, as with real options, a project is viewed as a process that managers can continuously reshape in light of technological or market changes (Kumbaroglu et al., 2008). Recently, attempts were made to combine these real options and to evaluate technology (Boer, 2000; Li & Chen, 2006; McGrath & Nerkar, 2004; Vega-Gonzalez et al., 2010; Cheng, Jiang, & Liu, 2015). Vega-Gonzalez et al. (2010) suggested a methodology for precompetitive technology valuation based on the identification of specific value points (SVPs) related to its development. Since each SVP has distinct features, they proposed a divergent approach at each SVP, which is similar to the cost and market approach. Li and Chen (2006) assumed that the value is the summation of the cost perspective, income perspective, and real option perspective for considering cost and time depending on the cases.

All perspectives of valuation have advantages because with the cost perspective, information can be obtained easily, whereas real options provide opportunities for decision-making against the change of market circumstances, and the market perspective is effective when many transaction data are available. However, in this study, the income perspective was applied because it is regarded as a practical method, although it is difficult to define the discount rate and level of contribution by the technology. This paper's aim is to overcome this problem by constructing relevant indicators and determining important factors, such as the size of the profit, the duration of the profit, and the discount rate with a scoring model and a weighted sum of indicators. Moreover, this paper suggests a guideline in the form of indicators and evaluation methods for calculating a future cash flow via technology by considering the intrinsic characteristics and marketability of technology. It can be helpful to estimate a future cash flow and interest rate for applying the income approach while avoiding biased estimation resulting from subjective inference. In particular, the future cash flow of technology is estimated by considering the correlation between technological characteristics and marketability. It reduces the gap between technology and the market, and it furthermore satisfies all of the needs of the buyers and suppliers who are transacting technology.

2.3. *Taguchi loss function*

Taguchi's loss function provides an effective means of quality engineering. Deterioration occurs when a product deviates beyond a specified limit, thereby becoming unacceptable products (Pi & Low, 2005; Ree, Park, & Yoo, 2014). Taguchi suggested a specific measure for the acceptability of a characteristic to indicate that the deviation from the characteristic's target value results in a loss and a higher quality measurement is one that results in minimal variation from the target value. For example, the loss is zero when the measurement of the characteristic is the same as that of the target value. Loss can be measured by using a quadratic function in three types of formula (1) the-smaller-the-better, (2) the-nominal-the-best, and (3) the-larger-the-better. Also, an action is taken to systematically reduce the variation from the target value (Kethley & Waller, 2002).

For 'the-smaller-the-better' type, the quality loss function is as follows:

$$L(y) = ky^2, \tag{1}$$

where y is the quality characteristic and the target value is zero and $L(y)$ is a quadratic function resulting from a reduction operation of the Taylor series development of elements defining quality loss (Cristian & Popescu, 2012). For 'the-nominal-the-best' and 'the-larger-the-better', the functions for quality loss are shown in formulas (2) and (3):

$$L(y) = k(y - m)^2, \tag{2}$$

$$L(y) = \frac{k}{y^2}, \tag{3}$$

where m is the nominal value of magnitude y and is considered as a target value and k refers to a proportionality constant, of which the value depends on the economic impact of a quality criterion (Cristian & Popescu, 2012). This approach has been frequently applied for robust design. It can optimise the product-line design and the process conditions because it can provide high-quality products at low development costs (Tsai, Liu, &

Chou, 2004). Since the Taguchi approach can conduct experiments with high efficiency to reduce experimental costs, the best combination of manufacturing factors can be determined through orthogonal arrays (Taguchi, Elsayed, & Hsiang, 1989). In this study, a modified Taguchi loss function is proposed to estimate the technological impact by predicting the social loss caused by defects of the technology. The function is converted to economic impacts of technology and is finally aggregated to the monetary value of information security technology. In particular, it is appropriate to utilise 'the-larger-the-better' type function since the degree of information security (performance characteristic) is larger; the loss is thus smaller and better.

3. Research framework

3.1. *Basic concepts*

In general, most approaches for technology valuation focus on the value of technology and its market value. However, the social and economic impacts of the technology must be considered for the valuation of information security technology because unexpected quality flaws in such a technology can incur considerable social loss. Thus, this paper proposes a new method for the valuation of information security technology that includes both the income approach and the Taguchi loss function. First, a technology evaluation is conducted to appraise the original value of technology. Then, several indicators that together serve as an adjustment factor are calculated from the technology evaluation and used to adjust the size of the expected income of the technology through market evaluation by linking technology factors and market factors. Then, the technology's monetary value is estimated by the income approach. At this time, after estimating the expected profit of products and services according to the amount of profit and the time taken to make the profit, the profit is converted to an expected profit of technology through the result of technology evaluation. In addition, the impact of the technology is calculated through the modified Taguchi loss function. The definitive value of technology is finally estimated by integrating the monetary

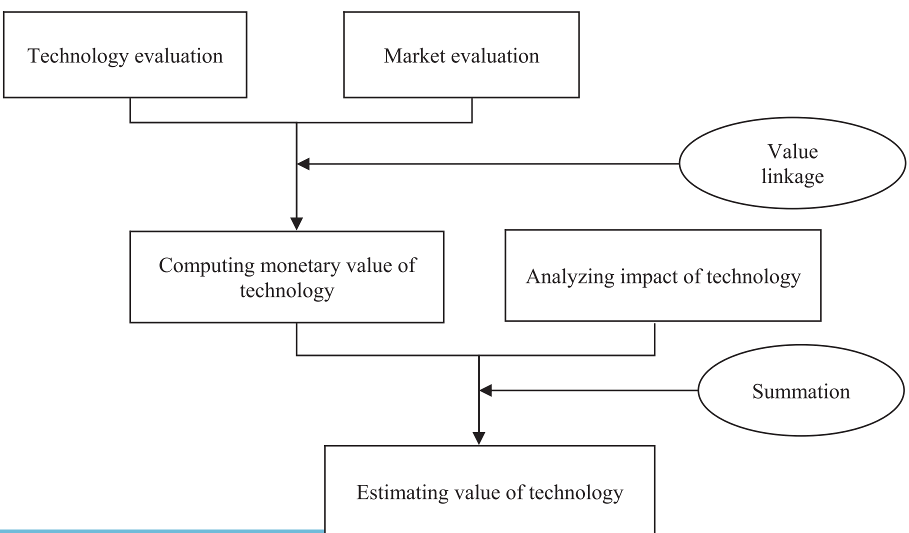

Figure 1. Overall process of the proposed technology valuation approach.

value from the income approach with the impact derived from the quality loss function. The overall process of the proposed approach is shown in Figure 1.

In particular, in the process of estimating the monetary value, the evaluation of technology factors is linked to the measurement of the technology's market value. Two significant factors are now considered, including the 'form of value' factor and the 'value measure' factor. The form of value factor shows the economic formation of the technology value and can be divided into cost reduction and benefit creation. The value measure factor is used to determine the information that is necessary to measure the technology value. It is categorised into the size of the benefit, the period of the benefit, and the risk factors. The relation between the form factor and the measurement factor is shown in Figure 2 and is used to calculate the adjusting factor during the marketability evaluation. When adjusting the profit flow of the technology and product, a weight should be applied to the technology factors by reflecting the characteristics of the technology and industry.

3.2. *Detailed process*

3.2.1. *Technology evaluation*

The technological value is evaluated using technological indices in terms of the basics of the technology and its application. The distinct characteristics of information security technology and all indicators are explained in Table 1. The intrinsic value of technology is evaluated through five indicators: innovativeness, exclusiveness, potential, technology level, and life expectancy of the technology. These are used to adjust profits by the sales of the product or service of which the technology is applied to, except for the life expectancy of the technology. The life expectancy shows the duration for which profits can be made by the technology and is utilised to define the duration of cash flow for the technology.

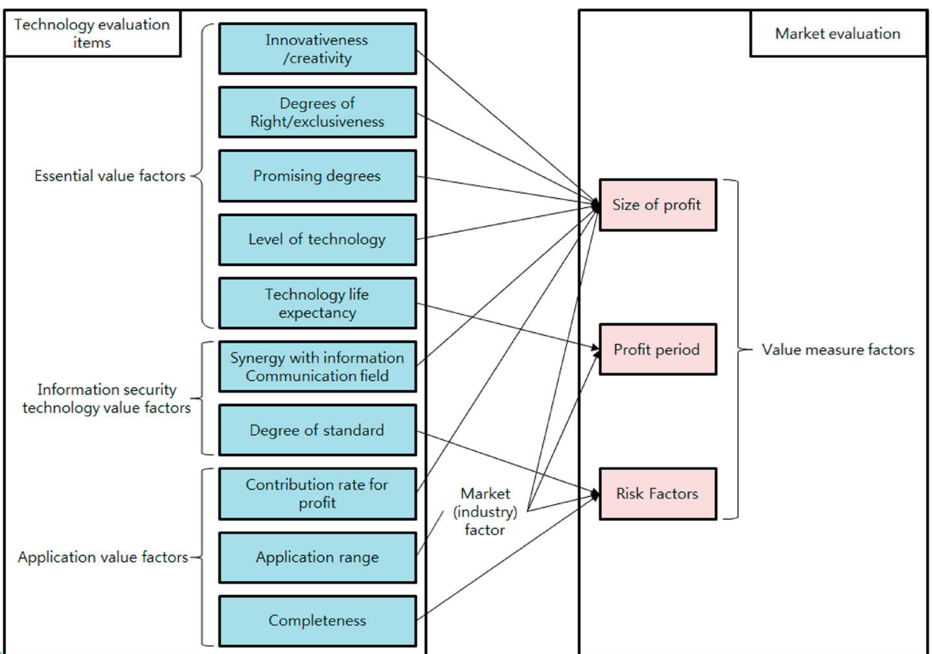

Figure 2. Linkage structure of technology and marketability.

Table 1. Technology indicators.

Indicators			Operational definition	Input metric
Intrinsic factors	Innovativeness		Evaluate difference from existing technology and predominance of technology with similar technology	Score
	Exclusiveness		Evaluate measure of patent binding force of certain technology compare with same type of technology	Score
	Potential		Evaluate impact of the technology on development or advancement of future technology	Score
	Level of technology		Evaluate technology's technical completion and reflection of recent technological trend	Score
	Technology life expectancy		Shows life of certain technology until substitution of advanced technology or not able to bring any more benefit.	Year
Information security technology – specific factors	Synergy of information security technology and ICT		Reflect resonance characteristic of information security technology with ICT to evaluate influence on other ICT	Score
	Standard	Compatibility	Check whether a technology coincide with standard of similar technology	Score
		Standard possibility	Evaluate possibility of implemented technology becoming international standard	
Application factors	Contribution rate for profit		Measure contribution of technology for creating value (Expected profit)	Percentage
	Application range		Evaluate number of technology classification and industries where use technology	Numbers
	Completeness		Measure satisfaction of requirements when applying technology into products and services	Score

In addition to the life expectancy of the technology, the income contribution rate and the implementation range indices are evaluated using the scoring model. Each score in the indexes is determined with a 5-point scale based on a predefined guideline to objectively evaluate the technology.

The unique characteristics of information security technology are presented as the indicators of the synergy effect with information technology and compatibility. The synergy effect can adjust the size of profit because it is possible to enlarge the market size using the information technology. The compatibility between the information security technology and other technologies demonstrates the possibility of an international standard or concurrence with an existing standard, which satisfies the demands of the consumer and increases the likelihood for adoption in a market. Thus, the indicator can play the role of adjusting the interest rate in the cash flow of a product or service. The application value is evaluated using three indicators: profit contribution rate, range of application, and completeness. Among these, the profit contribution rate is important because it serves to convert profit from a product or service to an income using the embedded technology. This indicator makes it possible to estimate the actual income from the technology and is measured according to years rather than a score. For the application range, the technology classification and industries in which the technology is used are considered. Among the technology factors, innovativeness, exclusiveness, degree of potential, level of technology, synergy, standard, and completeness are measured as a score ranging from 1 to 5. Technology life expectancy is measured in years. The contribution rate for profit and the application range are measured in percentage and numbers, respectively.

3.2.2. *Market evaluation using the income approach*

Based on the results of the technology evaluation, the monetary value is estimated using the income approach in this module. First, the expected profit flow of the product and service is calculated considering the range of application, technology life expectancy, compatibility, completeness, and ratio of ordinary profit. Then, the expected profit flow of technology is estimated through the converting process from the profit flow of a product with a technology contribution rate that comprises a portion of profit from the technology within the entire product's profit. Then, the profit flow of technology is reconciled with the adjusting factors that are composed of indicators for technology evaluation: innovativeness, exclusiveness, degree of potential, level of technology, and synergy effect with IT. Finally, the current value of the adjusted profit becomes the definitive value of technology that is computed with the discount rate; the detailed process is explained below (Figure 3).

Before estimating the profit flow of technology, the expected profit flows for a product in which the technology is applied are calculated in accordance with the technology life expectancy and application range (see Figure 4). First, the size of the market related to the products or services in which the information security technology is applied is identified by years, and the application range helps to determine the market size at the time. It is possible to generate one or more profit flows for the product or service depending on the number of applications while also extending the market size. Next, the annual market share during the expected lifespan of the technology should be investigated so as to predict the market size for which only the specific technology is applied. Then, the flow of sales is estimated by multiplying the market size by the market share according to years. Subsequently, the ratio of ordinary margins enables the expected profit flow of the product or service to be finally estimated. In accounting terms, the types of profit can be divided into business profit, ordinary profit, and net profit. The net profit can contain some irregular factors; this research therefore uses ordinary profit, which can be measured from the business analysis data provided by the Bank of Korea or from a press release by the company.

To estimate the sales of the product, the market size of the service market and the security technology that has been implemented as a product must be determined. The market share rate of the product is estimated and applied, and the life expectancy of the technology is estimated for each year. The sales flow in each year can be calculated by multiplying the size of the market and the market share. Finally, the profit flow for the product is calculated using the ordinary profit in the sales of the product industry from the sales flow that was previously calculated.

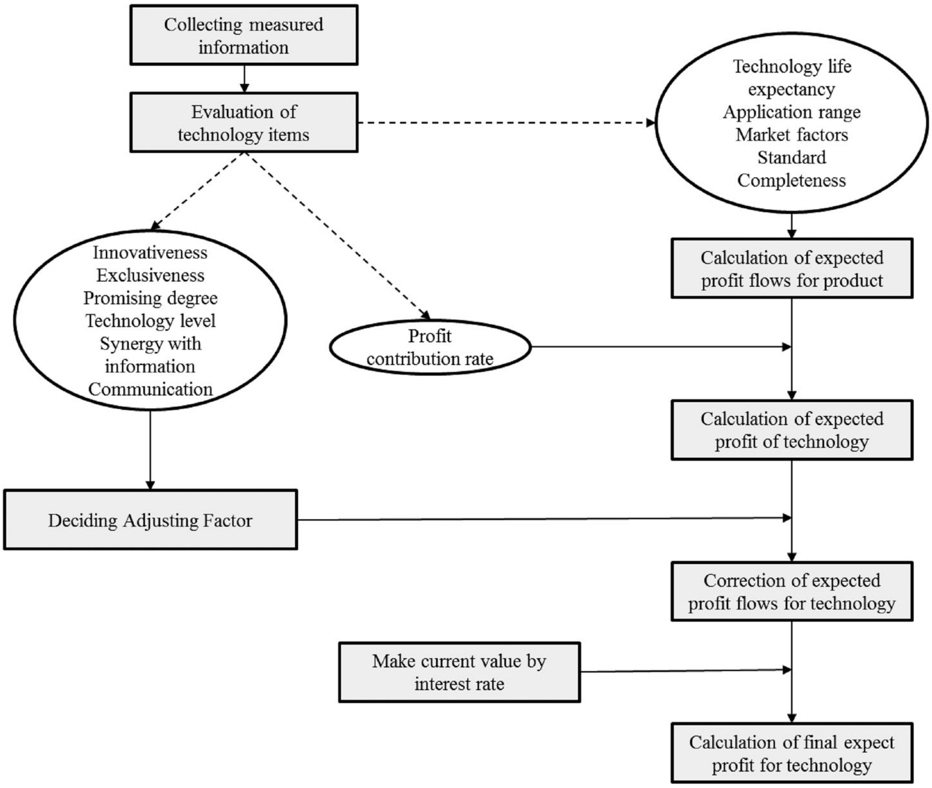

Figure 3. Process for marketability evaluation based on technological evaluation.

To determine the technology's economic worth, the expected profit flow of the product or service is multiplied by the profit contribution of the technology to deduce the expected profit. The contribution rate of the profit from the technology involves estimating or measuring the contribution rate of the profit from many data points as well as comparing the contribution factors (work, capital, and other technology) by sourcing an expert's

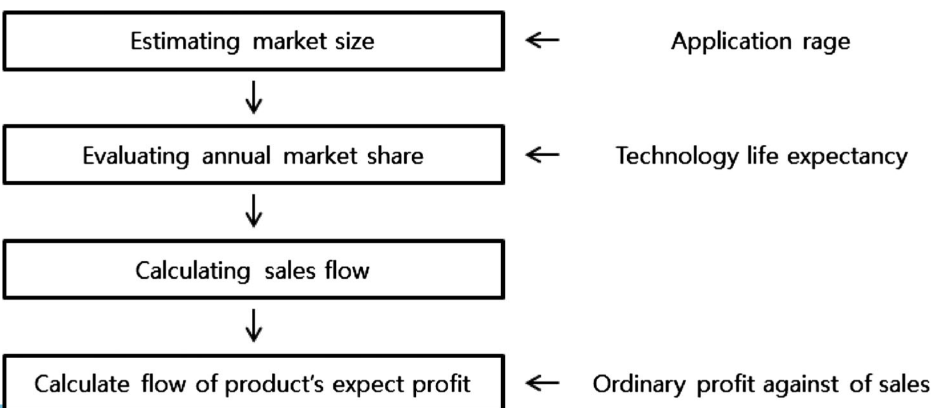

Figure 4. Process for estimating expected profit flow of product.

Table 2. Adjustment factor through sum of weight.

Sum of weight	Adjustment factor	Sum of weight	Adjustment factor
min $\sim f(1)$	0.6	$f(4) \sim f(5)$	1.0
$f(1) \sim f(2)$	0.7	$f(5) \sim f(6)$	1.1
..	0.8	$f(6) \sim f(7)$	1.2
$f(3) \sim f(4)$	0.9	$f(7) \sim f(8)$	1.3
		$f(8) \sim$ max	1.4

opinion. Information security technology can be applied to a large amount of software; thus, it is possible to expect a high-profit contribution from the technology for a service or product.

The expected profit flow that has been pre-calculated for the technology only reflects the market value factors and does not include the technological factors. Therefore, the profit flow needs to be corrected by applying the technology evaluation results. The innovativeness, exclusiveness, degree of potential, synergy of information security technology and the information communication field, and standard and completeness that are measured are multiplied by the weight of each index to calculate the weighted sum. The weight of each indicator is calculated through pairwise comparison as follows: (1) the technology indicators are paired and compared to construct the matrix; (2) the sum of the rows will be calculated according to the results of the paired comparison; (3) each sum of each row is utilised to divide the rows and form a standardised matrix; and (4) the average of each column in the standardised matrix becomes the final weight. The weighted sum is used to reconcile the expected profit flow for the technology as an adjustment factor, with the aim of considering the marketability as well as the value of the technology itself. When selecting the adjustment factor, the guideline for calculation is provided as follows because the range of the adjustment factor differs according to the weight, as shown in Table 2.

The expected profit flow should be discounted to provide the current value using the discount rate; then, the sum of all future cash flows becomes the net present value of the technology. Since the discount rate reflects the macroscopic conditions of the market, the average interest value during the technology's lifespan can be modified in accordance with the market structure or other environmental factors. As mentioned above, the compatibility and completeness factors affect the discount rate, and it is thus possible to control the discount rate for each technology. The results of the 5-point scale for the standard and completeness are added to the weight of each index, and thus a modified rate is applied to discount the future cash flow (profit flow of technology), as shown in Table 3.

Table 3. Correction of discount rate through sum of weight.

Sum of weight	Discount rate (%)	Sum of weight	Discount rate (%)
More than 1 less than 1.44	13	More than 2.78 less than 3.22	17
More than 1.44 less than 1.89	14	More than 3.22 less than 3.67	18
More than 1.89 less than 2.33	15	More than 3.67 less than 4.11	19
More than 2.33 less than 2.78	16	More than 4.11 less than 4.56	20
		More than 4.56 less than 5.0	21

According to the National IT Industry Promotion Agency in South Korea, the weighted average cost of capital of the industry, in which a technology similar to the target technology is applied, needs to be applied while also applying a technology valuation discount rate. In addition, the agency categorises small- and mid-sized IT companies according to sales, and a 2–5% risk premium is applied. The actual discount rate range is 12.3–21.4% due to the structure. Therefore, the medium value of 17% should be set as the baseline, and the control range is set to 25% of the discount rate (discount rate of 17 ± 4%, which gives 13–21%).

3.2.3. *Technological impact analysis using the Taguchi loss function*

If the information security technology does not work well, a massive economic loss will be made due to the leakage of information to other organisations or damage to customers' information, such as with cyber terrorism (Hesamamiri, Mahdavi Mazdeh, Jafari, & Shahanaghi, 2015). Therefore, the technological impact of information security must be analysed by quantitatively measuring the social and economic loss when security fails due to an error in information security technology. Accordingly, this paper suggests a model for measuring the social loss caused by technological defects; such loss is regarded as the technological impact through modifying the Taguchi loss function.

Even though the Taguchi loss function is usually used in managing the quality of the product, the aim of this paper is to utilise the Taguchi loss function to evaluate the technological impact and to show the massive social loss due to the lower level of security. As the level of security decreases, the amount of social loss increases. Thus, the damage that results from the failure of information security concurs with the 'larger-the-better type' shown in Figure 5 and is then modelled according to the following processes.

To estimate the Taguchi loss function, it is important to define the quality characteristics (y) (e.g. diameter, concentration, etc.) and proportionally constant (k), which will be calculated at the next step. The quality characteristics are defined according to the level of information security and are measured in terms of the confidentiality, integrity, and availability, which are core elements for security. After evaluating each element according to a 10-point scale, weights are given to each element, and the weighted sum is used to provide the level of security for the technology. Confidentiality is a term used to refer to the protection of the data content to provide access to authorised persons and prevent access from unauthorised users. Integrity is a term used to indicate whether the contents of the information are sent

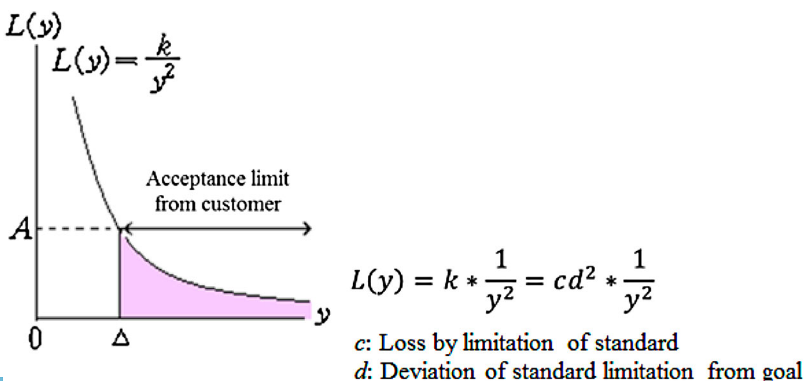

Figure 5. The-larger-the-better characteristic loss function.

correctly to the corresponding party, and the contents are only modified in an authorised manner by an authorised user. Availability is a term used to refer to the data, including information and information systems that should be accessible for authorised users whenever and wherever they are needed.

One of the critical parameters is the proportionality constant k, which is derived by multiplying consumer loss (c) by the square of deviation (d) between the target value and the specification limit as follows:

$$k = cd^2. \tag{4}$$

Assuming that the loss of the target rate due to the limitation of the standard is 0, the actual value in the limitation of the standard and related unit loss is estimated as c. In this case, a similar case study was investigated to estimate the parameter. When loss and damage occur due to the use of a similar technology, the level of technology is defined as a specification limit (lower limit). At this time, the security level of a similar technology is evaluated as the target technology. In addition, the deviation of the target value and limitation of the standard (d) is calculated as the difference between the security level of a similar technology and that of the target value of the technology security level from 10 points.

The unit loss cost of the technology $L(y)$ is derived from the security level and estimated parameters multiplied by the number of users, and it leads to the final impact of technology. To calculate the per capita loss cost compared to the unit loss $L(y)$ at the specific technical level, the parameter is estimated after conversion to the per capita loss cost in the case where the loss is estimated for a similar technique. The per capita loss is the loss cost for each person, and it is multiplied by the number of users, resulting in total loss caused by failures in information security.

4. Case study

4.1. *Case overview*

The suggested approach to evaluating and selecting information security technology is applied for a case study of the 'safe symmetric key algorithm for primary electricity power and electromagnetic wave side channel attack' technology. To analyse the case more accurately, a 'symmetric key algorithm for side channel attack' patent (KR 2011-0047064) is selected. This technology prevents a side-channel attack that extorts the secret key through the additional information (process time, electricity consumption, microwave occurrence, and result from injection errors) produced while running an encryption algorithm in a small device such as a smart card. After the attack was first identified in the late 1990s, the industry incorporating the smart card recognised the seriousness of the side-channel attack and then reacted to the attack.

Among such diverse types of side attacks, this patent is related to the algorithm used to respond to the electric power and electromagnetic wave side-channel attack. The Academy, Research Institute, and Agency (ARIA) algorithm is implemented against various forms of electrical power and electromagnetic wave side-channel attacks. This algorithm utilises a random middle value of the ARIA algorithm to mask various forms of electrical power and electromagnetic wave side-channel attacks. Two approaches can be used to respond to the electrical power and electromagnetic wave side-channel attacks. The first approach involves the removal of the connectivity with the actual value while running the encryption algorithm, which is referred to as 'masking'. The second approach involves preventing the prediction of the electrical consumption through the use of an encryption algorithm, which is referred to as 'hiding'.

Compared to other masking techniques, this technology can reduce the number of overheads and consumes less battery power while also providing faster security than the existing SEED algorithm. However, the Cryptographic Research Institute owns most of the original patents; RiScure and Brightsight have developed side-channel analysis equipment. In addition, many countries have developed various technologies to respond to a subchannel attack, so the current market share seems to be low. Nevertheless, the technology is expected to be applied and combined in the wide range of elemental technologies due to its high efficiency in arithmetic operation, memory, and power consumption. Based on the domain knowledge of experts and data analysis, technology evaluation is performed, as shown in Table 4.

4.2. *Market evaluation using income approach*

The expected profit flow of the product is based on the number of product sales and the rate of ordinary profit for four years, which were determined from the life expectancy of the technology. Many products are associated with the authentication for encryption keys such as smart cards, hardware security modules, the one-time password device, and the public key infrastructure. In this research, the target market is limited to smart cards and the hardware security model. Their sales are integrated and become the expected profit of the product or service. The ordinary profit was calculated by using the average rate for the last four years in the field of industry involving the product, and thus the average ratio of ordinary profit is calculated as 7.1025%. In 2012, the expected profit of the product was USD 1572, and it was expected to decrease to USD 1237 in 2016 (Korea Information Security Industry Association, 2013). The profit contribution rate of technology is 14% and is multiplied by the expected profit flows of the product or service (sales) so as to calculate the expected profit from the technology. As a result, in 2012, the expected profit of a product was converted to USD 219,988 as the profit flow of technology, which would become USD 173,034 million in 2016, as seen in Table 5.

The weighted sum of indicators (innovativeness, exclusiveness, degree of potential, the level of technology, and synergy effect with IT) is 3.9767, and thus the adjusting factor is 1.2 (see Table 2). Accordingly, the expected profit flow for the technology was adjusted to

Table 4. Results of technology evaluation.

Items	Details	Score (or %, years)	Weight
Essential value factors	Innovativeness	3	0.15
	Exclusiveness	2	0.07
	Degree of potential	5	0.38
	Technology level	4	0.30
	Technology life expectancy	5	
Information security technology value factors	Synergy of information security technology with IT	3	0.11
	Standard	4	0.875
Application value factor	Contribution rate for profit	14	
	Application area	1	
	Completeness	5	0.125

Table 5. Expected benefits of the side-channel attacks technologies (in USD).

Year	2012	2013	2014	2015	2016
The expected benefits of technology	219,988	224,680	167,702	170,318	173,034

USD 263,985 in 2012 and was expected to be USD 207,640 in 2016 (Table 6) after multiplying the adjusting factor by the expected profit flow derived at the prior substep.

To determine the discount rate that reflects the indicators affecting the risk factors for technology development, the weighted sum between the compatibility and the completeness is 4.15; thus, the discount rate is determined to be 20% (see Table 3). The final expected profit of the information security technology became USD 955,721 at the end of 2011 by discounting the future value from the current value with the discount rate (see Table 7).

4.3. *Technological impact analysis using the Taguchi loss function*

The target technology information such as the power consumption or input time for the encryption algorithm should not be disclosed to outside parties. It is thus important that the content of the transmitted data does not change, and that the confidentiality and integrity are highly weighted (see Table 8).

This research attempts to estimate the loss factor by selecting the case where memory hacking is used for a side-channel attack. The components susceptible to many side-channel attacks include smart cards, IC cards, Internet of Things (IoT), etc., and the most similar case is where memory was hacked. Memory hacking is a crime in which account numbers and passwords are stolen by hacking the encryption system. Hacking modifies the data in the memory and traditional hacking methods usually focus on withdrawing an account password from external memory hacking, such as by installing a programme, a secret door, and an account and password, as well as an amount that is to be withdrawn from the recipient to manipulate the recipient data. Memory hacking usually occurs due to a malware hack of security products, targeting financial institutions. The failure in security from a side-channel attack that corresponds to the technology can be seen as a failure of the security mechanism. The side channels corresponding to the loss contribution of technology is 30% of the total loss. According to an analysis of the 'electronic banking fraud data' from the Korea Internet & Security Agency National Police Agency, a total of 560 memory hacking cases occurred from 2013 to June 2014, and the amount of loss at that time was approximately USD 2,744,672 (Kim, 2014). The average amount of loss per case appeared to be USD 4901.2. The security level of the technology when the fraud occurred is a weighted average of 2.5 points as shown in Table 9.

From the standard limits and the deviation estimation previously calculated, the security level at the time the damage occurs is 2.5 points, and 7.5 has been evaluated as the deviation between the specification limits of the target.

Table 6. Corrected expected profit of side-channel attack corresponding technology (in USD).

Year	2012	2013	2014	2015	2016
Corrected expected benefit of technology	263,985	269,616	201,243	204,382	207,640

Table 7. Results of technology valuation (in USD).

Year	Sales	Business profit	Expected profit	Expected profit (adjustment)	Current value (2011)
2012	22,139,574	1,572,463	219,988	263,985	219,988
2013	22,611,784	1,606,002	224,680	269,616	244,680
2014	16,877,560	1,198,729	167,702	201,243	167,702
2015	17,140,827	1,217,427	170,318	204,382	170,318
2016	17,414,125	1,236,838	173,034	207,640	173,034

- $d = 10$ (target value) – 2.5 (security level at the present) = 7.5 points
- Loss cost and security level at the time, c can be estimated through deviation d

$$L(y) = \ 4901.2 = k \times \frac{1}{y^2} = cd^2 \times \frac{1}{2.5^2} = c \times 7.5^2 \times \frac{1}{2.5^2}.$$

- $c = 544.58$ has been estimated, the estimated loss function equation is as follows
- $y = 8.1$ = the security level of the technology for defence against side-channel attack = the weighted average of each index for evaluating security level (Table 8)

$$L(y) = \ k \times \frac{1}{y^2} = cd^2 \times \frac{1}{y^2} = 544.58 \times 7.5^2 \times \frac{1}{8.1^2}.$$

The unit loss $L(y)$ is calculated as USD 466.89 by entering the technology score in the estimated loss function equation. In 2014, 297,000 cards were not converted to IC cards, and 40% of these cards are not counted because they have a small amount of account balances which are under 10 USD. As a result, the technological impact is expected to be USD 83.20 million.

4.4. *Technology valuation*

Consequently, the final value of this technology is USD 0.96 million, the technological impact is USD 83.20 million, and the estimated value of technology was a total of USD 84.16 million. The technology is evaluated as a high application and growth potential technology that can compensate for the weaknesses of the existing technology such as memory and power efficiency. Also, the market size of the electronic trade market such as smart cards and IC cards results in vulnerabilities to the side-channel attacks that are continuously conducted. It is thus possible to evaluate the economic value of the technology as high due to the needs for the technology. However, once a side-channel attack occurs, the loss size

Table 8. Side-channel attack security evaluation of the corresponding technology.

Level measurement index	Score	Weight
Confidentiality	9	0.5
Integrity	6	0.2
Availability	8	0.3
Average	7.7	8.1 (weighted average)

Table 9. Security assessment of the damage at the time of memory hacking techniques.

Level measurement index	Score	Weight
Confidentiality	3	0.5
Integrity	2	0.2
Availability	3	0.3
Average	2.7	2.5 (weighted average)

per case is considerable, so the technological impact of the technology seems to also be very large.

5. Discussion

Several issues should be pinpointed from the viewpoint of the assessment process and results. The first issue is to set criteria for technology and market evaluation on the basis of evidentiary sources such as a technical report and a market prediction report. Although the value of technology was quantitatively estimated by the market approach and Taguchi loss function based on guidelines, the proposed approach may require a detailed investigation to assess the technological and market characteristics. Thus, the assessment process based on indicators with base literature requires much more elaboration because it could be considered difficult and complex for evaluators, and it leads to biased and wrong prediction results. With regard to the assessment process, another issue is estimating socioeconomic loss through the Taguchi loss function, which applied the number of customers damaged by the side-channel attack. To calculate the total loss by failures in information security more accurately, the range of users can be extended to clients of firms, which helps evaluators to measure the diffusion of technology in a broader range.

Second, from the viewpoint of results, it has become necessary to develop relevant technology for the purpose of responding to the side-channel attack that was founded so as to have a great effect on society. With the increased importance of evaluating information security, demands for the development of standards related to the evaluation and validation for security have also been continuously increasing. Since 1998, there have been many side-channel attacks, and they are evolving based on machine learning and deep learning. In particular, common criteria and the Federal Information Processing Standard Publication 140, which are security requirement cryptographic modules, are specified and updated in succession. This means there is increased interest in the standardisation of technology for responding to the side-channel attack, and there are requirements to develop and make relevant strategies. Many attempts to prevent and deal with side-channel attacks have been made (Arp, Yamaguchi, & Rieck, 2015; Chen, Wang, Wang, & Zhang, 2010; Standaert, 2010; Wang, Yan, Cai, Zhou, & Yang, 2017). Wang et al. (2017) explored the methods of exploiting the power grid-induced noise, and Pammu, Chong, and Gwee (2017) proposed a highly secured state-shift local clock countermeasure technique to hide the physical leakage against side-channel attack. Matsubayashi, Guntur, and Satoh (2017) conducted security evaluation of cryptographic modules against side-channel attack using a biased data set. Furthermore, as the type of side-channel attacks based on deep learning evolves, a new technology must be developed or existing technology may be improved to cope with standardisation with regard to the side-channel attack and analysis. In addition, technology has not reached the end of its life cycle, and the market size is expected to increase. Thus, further efforts are needed to develop a commercial model, test bed, and mass-production model other than the basic technology.

The proposed approach is meaningful, as it is a customised valuation approach reflecting technological features. First, previously, the unique characteristics of technology were sometimes neglected, and their ripple effect was not sufficiently reflected in the value of technology, as the focus was limited to only deriving a monetary value. Consequently, traditional approaches are not appropriate to perform technology valuation of information security technology, thus presenting underestimated technology value. However, this study considers the distinct features of technology and suggests a customised technology valuation process. Second, the Taguchi loss function enables analysers to easily identify the massive socioeconomic effect of small failures in operating technology without the need for a complicated process. Specifically, it is appropriate to investigate the impact of technology itself because the level of information security was measured rather than the specification of the product, and the total loss was calculated by multiplying the unit loss by the users of technology. Whereas traditional approaches cannot estimate the whole value of the information security technology, the proposed approach has a critical advantage in including both monetary value and social impacts, enabling one to correctly evaluate the kind of technology that has considerable impacts on society. Moreover, the Taguchi loss function is modified for the best fit in the inherent characteristics of information security technology. In addition, it can be customised and extended to other technology by changing indicators for evaluating attributes of technology. Finally, the proposed approach can evaluate the socioeconomic impacts of technology itself more accurately by setting a limit on the technology rather than an industry level. Evaluating the technology at the industry level may bring about an overestimation in the technology value and wrong strategies and policies for firms and governments. Recently, with the increasing importance of information security, this approach is appropriate to assess technology value, which will lead to establishing practical strategies for technology development or market penetration.

Thus, this framework offers objective and more accurate results to support decision-making for the R&D and business plan. It also considers the results of the socioeconomic technological impact analysis when a technology has been implemented and not merely for the value of technology itself. This is why the framework can be used as basic data to estimate a promising technology that can dominate high-value-added and future industries. The economic value is calculated by reflecting the link between technology and its marketability, so it is possible to provide quick and correct decision-making during technology industrialisation, technology transfer, and technology trade. In addition, it is important to back up data when distributing resources for projects in an organisation by comparing the results with those of similar technology tasks to evaluate the capability of the research institution for the target technology; this contributes to reviewing the efficiency and effectiveness of technology development through the appropriate distribution of resources for R&D by using objective data. Various technology indexes help to evaluate the value of the research project related to the technology and establish the direction of information technology policy.

6. Conclusion and future research

This paper suggested a technology valuation methodology that reflects the characteristics of information security technology through the income approach and the modified Taguchi loss function. The technology valuation factors were separated into essential value factors, value factors related to the information security technology, and application value factors. These factors were divided into 11 indicators and measured according to proposed guidelines with the aid of evaluation. The market value was estimated through an income approach while defining the profit size, period, and risk factors based on the relationship between the degree of technology and marketability. The technological impact was derived from the social loss caused by the faultiness of information security technology relying on the Taguchi loss function while reflecting the characteristics of information security technology that has a significant technological impact.

The aim of this research was to show a comprehensive methodology that involves both the qualitative evaluation and quantitative valuation of the technology. The value of the technology was qualitatively measured on the basis of the indicators for each value factor, and the guidelines based on accurate back data were provided for acquiring more objectiveness with five standardised points. This enabled the accurate calculation of the expected profit of the technology by combining the technology evaluation items and the expected profit of the product, as deduced by the market value including the size of the market, market share, etc.

The suggested approach in this paper can significantly contribute to the technology valuation research area because it is able to improve the accuracy of estimation through market approach and Taguchi loss function based on objective and distinct indicators and scoring process. These indicators considered all of factors influencing technology valuation by including the characteristics of technology and its applications. In particular, a market approach for extracting the value of technology was composed of analysis of technological ability and marketability, and relationship between them at once, which can reduce the possibility of a mistaken prediction. The transformed Taguchi loss function can contribute to deducing socioeconomic impact caused by degradation of security level in the form of monetary value. Since the definitive value of technology was finally derived by aggregating the results by the market approach and ripple effect analysis, it is able to generate results of valuation reflecting reality.

This study can be utilised in a wide range of industry by transforming several indicators related to unique characteristics of technology in context. It will be appropriate to assess the value of technology having a large impact on society such as national defence, artificial intelligence, nanotechnology, and ICT including IoT, big data, self-driving vehicle lately. Since the national defence technology is similar to information security technology in the way that it influences on society and finance at the national level, the proposed approach can be exploited to estimate the value of technology. In the case of ICT, it can be in the limelight due to the fourth industrial revolution because this technology is the foundation to realise the new industry revolution. That is why the suggested methodology for technology valuation assists to value of potential technology in ICT industry.

Although the proposed approach for technology valuation is systematic, it has some limitations which should be resolved in a future study. First, the accuracy can be reduced due to the lack of sufficient data on the target technology. At this time, it is necessary to investigate in detail the product or service that will be applied by the target technology, using technology or market domain experts. Second, the results of technology evaluation depending on scoring can be biased if they do not follow evaluation guidelines. The intention of this paper is to provide guidelines to help evaluators score objectively using indicators on the basis of accurate back data. Otherwise, the biased evaluation for technology may cause a gap when undertaking R&D or exploiting technology. Third, the user of technology is limited to private practitioners when estimating technological impact. If the range of the user is extended to the firm level such as individual firms and clients, it will be possible to identify the total impact of the technology. To overcome these limitations, indicators and guidelines to evaluate technology and marketability needs to be exquisite for adapting to a real circumstance in the future research. In particular, general users should be able to apply the proposed methodology easily without retrieving and investigating base materials in depth. In addition, it will be possible to prioritise research and development projects by utilising the definitive value of technology which becomes one of the influential indicators in the future research. The priority evaluation based on technology valuation established in this paper helps to make robust decisions in commercialising and transferring promising technology.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by National Research Foundation of Korea [grant number NRF-2017R1D1A1A09000758].

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